

## Measles Epidemic From Failure to Immunize

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During 1988 through 1990, California experienced its worst measles epidemic in more than a decade, with 16,400 reported cases, 3,390 hospital admissions, and 75 deaths. More than half of the patients were younger than 5 years; the highest incidence was among infants younger than 12 months. The epidemic centered in low-income Hispanic communities in southern and central California. The major cause of the epidemic was low immunization levels among preschool-aged children and young adults. Rates of complications, admission to hospital, and death were surprisingly high. Outbreak control efforts met with indeterminate success. Problems with these efforts included insufficient funding early in the epidemic and disappointing public response to community-based immunization campaigns. The cost of medical care and outbreak control for the epidemic is conservatively estimated at \$30.9 million. Unless the level of immunization in preschool-aged children is increased, this type of epidemic will probably recur.

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Historically, measles (rubeola) was a universal childhood disease in the United States, having an incidence rate approaching the birth rate. Following the introduction of the measles vaccine in the 1960s, the incidence of the disease fell 90%.<sup>1</sup> A rigorous enforcement of school and child care immunization requirements in the 1970s led to another 80% to 90% decrease in measles incidence.<sup>2</sup>

During the early 1980s California's measles incidence was at an all-time low of 1 to 3 cases per 100,000 population (Figure 1). From 1981 through 1987, an average of 457 cases per year were reported (range, 176 to 831). During this time, most of California's larger measles outbreaks occurred in secondary schools in which many students had entered school before immunization requirements were rigorously enforced.

In mid-1988, a different type of measles outbreak began in Los Angeles County. This outbreak was centered in low-income communities and primarily involved preschool children and young adults. The outbreak quickly

grew to be an epidemic, spreading to other parts of the state and producing 3,010 cases in 1989 (10.4 cases per 100,000 population) and 12,587 cases in 1990 (42.3 cases per 100,000). In this article we describe the epidemiology of California's measles epidemic in 1988 through 1990 and public health control efforts. Similar outbreaks occurred in many other states.

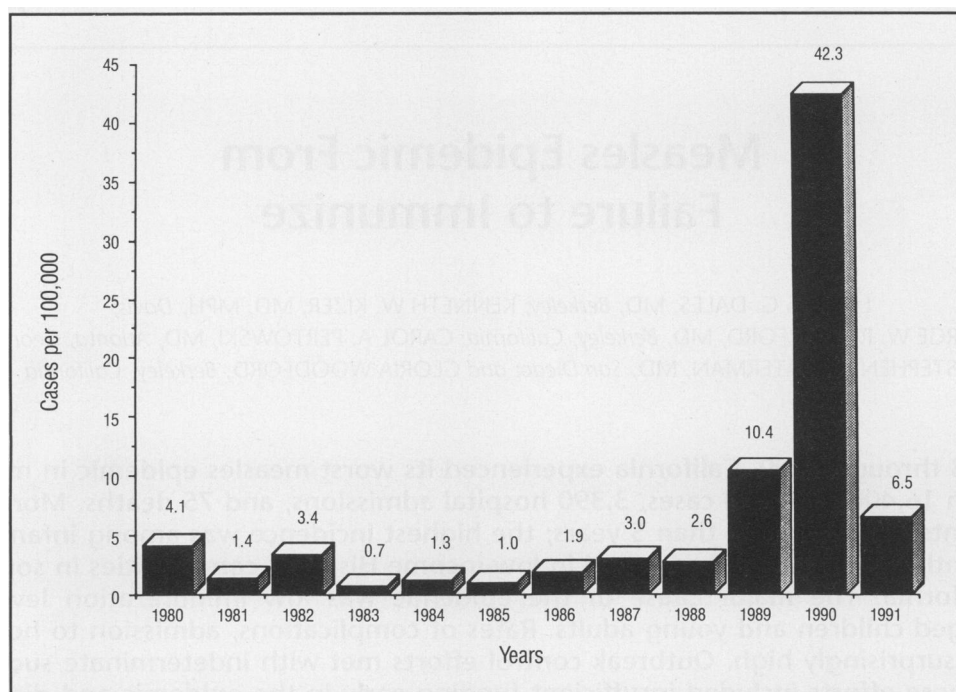
### Methods

Measles is a mandatorily reportable disease in California. Compliance with this requirement is judged to be good. Individual cases are reported first to the local health department on standard, state-issued forms; local health departments then report cases to the California Department of Health Services (CDHS). Disease reports contain demographic, clinical, and laboratory information as well as data on immunization history, source of infection, and measures taken to prevent secondary spread. These reports were our principal source of data.

To be included in this study, a measles case must be

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**Figure 1.**—Annual measles incidence rates for California increased dramatically in 1989 through 1991 from an all-time low in the early 1980s.

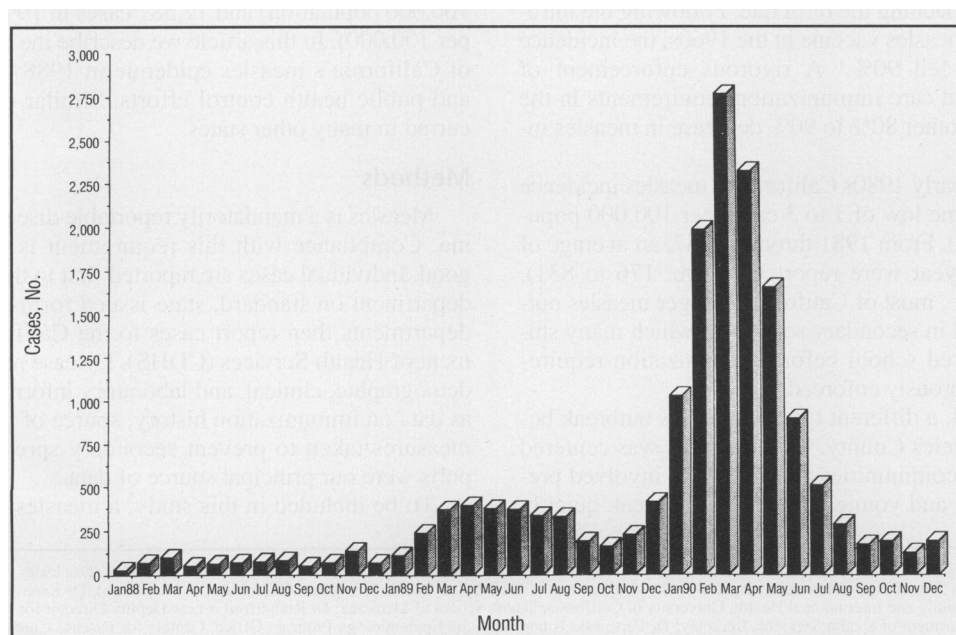
either laboratory confirmed or epidemiologically confirmed by virtue of meeting the federal minimum clinical criteria for measles—generalized maculopapular rash of at least three days' duration, notable fever and cough, coryza, or conjunctivitis—and being directly linked to at least one other case that meets the same clinical criteria or has been laboratory confirmed as measles.<sup>2</sup> Adequate measles immunization is defined as having a record show-

ing month and year of vaccination after the first birthday. Data from case report forms were entered into a dBase 3-plus format and analyzed using Epi Info 5.01B.<sup>3</sup>

## Results

### *Temporal and Geographic Course of the Epidemic*

From January 1988 through December 1990, there



**Figure 2.**—The number of reported measles cases greatly increased from the spring of 1988 through the summer of 1990.

TABLE 1.—Measles Cases by Geographic Region, California, 1988-1990

Region*	Measles Cases by Year					
	1988		1989		1990	
	No.	%	No.	%	No.	%
Southern California.....	689	86.4	2,632	87.4	9,113	72.4
San Joaquin Valley.....	10	1.3	248	8.2	2,553	20.3
San Francisco Bay Area and Central Coast..	92	11.5	99	3.3	621	4.9
Northern California and Sierras.....	6	0.8	37	1.2	300	2.4
Total.....	797	100	3,010	100	12,587	100

\*Southern California: Imperial, Los Angeles, Orange, Riverside, San Bernardino, San Diego, Santa Barbara, and Ventura counties. San Joaquin Valley: Fresno, Kern, Kings, Madera, Merced, San Joaquin, Stanislaus, and Tulare counties. San Francisco Bay Area and Central Coast: Alameda, Contra Costa, Marin, Monterey, Napa, San Benito, San Francisco, San Luis Obispo, San Mateo, Santa Clara, Santa Cruz, Solano, and Sonoma counties. Northern California and Sierras: all other counties.

were 16,400 cases of measles reported to the CDHS. Of these, 1,948 (12%) were laboratory confirmed. Figure 2 depicts cases according to month of rash onset, and Table 1 shows the regional distribution of cases.

In early 1988, most measles cases being reported to the CDHS were linked to secondary schools and colleges, as had been the pattern in previous years. In May and June 1988, a new pattern of measles outbreak appeared in Los Angeles County; young children in low-income communities suddenly became the predominant population affected. In the ensuing months, increased measles incidence appeared in other southern California counties. By early 1989, a measles epidemic was definitely under way, with the disease spreading throughout southern California and also appearing in the San Joaquin Valley. In late 1989 and early 1990, the epidemic accelerated in both southern California and the San Joaquin Valley, with localized outbreaks occurring in northern California. The epidemic peaked in March and April 1990 (2,757 and 2,313 cases, respectively). The incidence decreased dramatically in the second half of 1990 (Figure 2) but remained above pre-epidemic levels until the spring of 1991. A total of 1,963 cases occurred in 1991, with 1,140 and 611 cases being reported in the first two quarters of the year, respectively, and 212 cases in the second half of the year. The case total for 1992 was 61, an all-time low.

While the 1988 incidence and case total were not significantly different from those of 1987, the initial out-

breaks and transmission patterns that led to the notably increased 1989 and 1990 caseload began in mid-1988. Thus, 1988 is included as the first year of the epidemic.

#### Age, Sex, and Race or Ethnicity of Cases

Table 2 shows California's measles cases and incidence by age for the 1980s. From 1988 through 1990, more than half of patients were of preschool age, compared with 30% in the pre-epidemic period. Both before and during the epidemic, infants younger than 12 months had the highest incidence, followed by children aged 1 to 4 years. Figure 3 shows the age distribution of cases in infants and children younger than 2 years for the epidemic period.

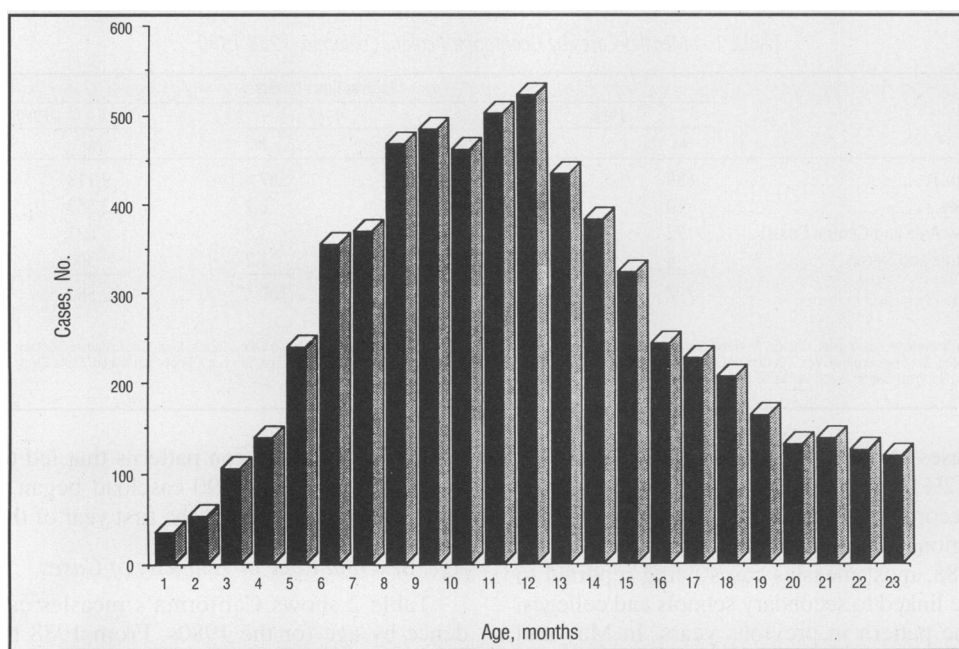
At some points in the epidemic the preponderance of preschool-aged cases was particularly striking. For example, in Los Angeles County during the summer of 1988, more than 75% of reported cases were in children younger than 5; most of them were Hispanic. Also, in two local outbreaks affecting Samoan and Southeast Asian children, 65% and 87% of patients, respectively, were younger than 5 years.

Although race and ethnicity were not recorded for many cases, tabulation by surname indicated that 40% of disease instances were in persons of Hispanic and 5% were in persons of Asian or Pacific Island ancestry. Race was recorded for all Los Angeles County patients (6,286); among these, 10% were African Americans.

TABLE 2.—Age Distribution and Incidence Rates for California Measles Cases, 1980-1990

Age Group, yr	Measles Cases by Year								
	1980-1987			1988			1989-1990		
	No.	%	Average Annual Incidence Rate*	No.	%	Average Annual Incidence Rate*	No.	%	Average Annual Incidence Rate*
<1.....	503	12.2	14.3	128	16.1	31.0	3,081	19.8	363.1
1-4.....	738	17.9	5.4	232	29.1	12.1	5,181	33.2	131.3
5-9.....	523	12.7	3.7	65	8.2	2.9	1,297	8.3	29.2
10-19.....	1,476	35.8	4.9	219	27.5	5.7	2,207	14.1	27.4
≥20.....	776	18.8	0.5	153	19.2	0.8	3,787	24.3	9.0
Unknown.....	112	2.7	--	--	--	--	50	0.3	--
Total.....	4,128	100	2.0	797	100	2.8	15,603	100	26.2

\*Cases per 100,000 population. For multiple-year periods, midpoint population estimates were used.



**Figure 3.**—Cases of measles younger than 2 years were highest among 8- to 12-month-old infants during the 1988-1990 epidemic.

#### *Immunization Status*

Only 12% of patients aged 1 to 4 years had been immunized against measles, whereas 45% of 5- to 19-year-olds had been immunized. The remainder of the school-aged patients had either legally allowed exemptions to the school immunization requirement or, more often, school records showing the measles immunization missing or inadequately documented. Only 4% of patients older than 20 years had been immunized.

Among unimmunized patients aged 12 months and older, 1.6% had religious or philosophical beliefs against immunization and 0.2% reported a medical contraindication to immunization. The remaining 98% simply had not been immunized or could not document immunization.

#### *Source of Infection*

The source of infection was identified for only 21% of patients. Of these, 62% were infected in their own household or by a neighbor or friend; 16% were infected in medical care facilities; 14% were infected in child care centers, schools, or colleges; and 8% were infected in jails, prisons, or other detention facilities. For patients acquiring their infection at a medical care facility, the facility was a hospital three fourths of the time. A third of medical facility-transmitted cases involved patients infected in emergency departments. Only 0.8% of cases were thought to have been imported from outside California; 82% (106 cases) of these were from Mexico.

#### *Complications, Hospital Admissions, and Deaths*

Table 3 shows the frequency of selected measles complications by age group for 1987 through 1990. The data for 1987 are representative of previous years. Pneumonia and diarrhea were the most frequently reported complica-

tions. Complications were generally less frequent in school-aged children than for preschool-aged children or adults. In all age groups, pneumonia and diarrhea were more common than reported in pre-epidemic years.

For the pre-epidemic years 1981 through 1987, only summary data on admissions to hospital were available; 2.4% of 4,132 cases required hospital admission during this time. In contrast, more than 20% of cases reported in 1988-1990 required hospital admission (Table 4).

From 1988 through 1990, 75 patients with measles died, for an overall case-fatality rate of 0.5% (Table 5). Of these patients, 89% had pneumonia and 15% had encephalitis (4% had both). The most common cause of death was primary measles pneumonia leading to respiratory failure. The case-fatality rate for children aged 5 to 19 years (0.1%) was five to six times lower than that for preschool-age children and adults. Case-fatality rates by racial or ethnic group were as follows: Hispanic surname, 0.4%; Asian or Pacific Islander surname, 2.5%; all others, 0.3%. The high case-fatality rate among Asians or Pacific Islanders relates to two specific outbreaks that are discussed below.

#### *Institutional Outbreaks*

Although most cases in the epidemic were community acquired, outbreaks erupted in several institutions.

**Schools and colleges.** More than 3,500 cases (21%) involved schools. The vast majority of school-related incidents involved 1 to 3 cases, indicating that transmission in schools was not a major cause of the epidemic. Five junior and senior high schools had outbreaks of 10 to 20 cases each. In 1988 a multiple-school outbreak in Orange County resulted in 43 student cases; this outbreak primarily involved secondary schools. Eight colleges had out-

TABLE 3.—Measles Case Complications by Age Group, California, 1987 and 1988-1990

Complication by Age Group, yr	Measles Cases by Year						P Value
	Cases, No.	1987*		Cases, No.	1988-1990		
		No.	%		No.	%	
<b>Pneumonia</b>							
<1 .....	57	0	0.0	3,209	285	8.9	.008
1-4 .....	138	2	1.5	5,413	492	9.1	.002
5-19 .....	426	4	0.9	3,788	145	3.8	.002
≥20 .....	125	3	2.4	3,940	338	8.6	.01
All ages .....	746	9	1.2	16,350	1,260	7.7	<.001†
<b>Diarrhea</b>							
<1 .....	57	3	5.3	3,209	472	14.7	.05
1-4 .....	138	6	4.4	5,413	727	13.4	.002
5-19 .....	426	24	5.6	3,788	370	9.8	.02
≥20 .....	125	8	6.4	3,940	551	14.0	.02
All ages .....	746	41	5.5	16,350	2,120	13.0	<.0001†
<b>Otitis Media</b>							
<1 .....	57	8	14.0	3,209	237	8.0	.13
1-4 .....	138	14	10.1	5,413	411	7.6	.27
5-19 .....	426	4	0.9	3,788	66	1.7	.22
≥20 .....	125	0	0.0	3,940	18	0.5	1.00
All ages .....	746	26	3.5	16,350	732	4.5	.55†
<b>Encephalopathy</b>							
<1 .....	57	0	0.0	3,209	5	0.2	1.00
1-4 .....	138	0	0.0	5,413	11	0.2	1.00
5-19 .....	426	0	0.0	3,788	2	0.1	1.00
≥20 .....	125	2	1.0	3,940	8	0.2	.04
All ages .....	746	2	0.3	16,350	26	0.2	.49†

\*Information was available for only 92% of 1987 cases.

†Mantel-Haenszel summary  $\chi^2$  P value.

breaks ranging from 2 to 38 cases per college (127 cases total).

**Detention facilities.** A total of 23 outbreaks occurred in jails, prisons, or juvenile halls—1 in 1988, 4 in 1989, and 18 in 1990. These outbreaks ranged from 2 to 103 cases, with a combined total of 278 cases (1.6% of all epidemic cases). Of these, 98% (271 cases) were inmates. Four inmates died of respiratory complications, yielding a case-fatality rate of 1.5%.

**Medical care facility cases.** Of the epidemic cases, 554 patients (3.4%) were known to have acquired their

infection in medical care facilities. During the 27-month period from January 1988 through March 1990, 157 patients (46%) with infection acquired in medical care facilities were facility staff members. Because the epidemic caseload outstripped investigative resources by the spring of 1990, occupation was not determined during most of 1990, and medical staff cases could not be identified for this period.

Of the 157 medical facility staff members infected, 5% (8 cases) were 15 to 19 years old, 50% (76 cases) were 20 to 29 years, 40% (65 cases) were 30 to 39 years, and 5% (8 cases) were 40 or older. Nurses made up 26% (41 cases), 17% (27 cases) were physicians, and 10% (15 cases) were laboratory or radiology staff members; the remaining 47% (74 cases) had a variety of other jobs. For 84% of medical facility staff cases, the known or presumed exposure site was a hospital; 17% of these were thought to have been infected in the emergency department. Only 4% of the infected staff members had a documented history of measles immunization. Some health care workers continued working during their illness prodrome, exposing other staff and patients, but detailed information documenting staff-to-staff or staff-to-patient transmission is not available.

TABLE 4.—Measles Cases Admitted to Hospital by Age Group, California, 1988-1990

Age Group, yr	Measles Cases, No.	Admitted to Hospital	
		No.	%
<1 .....	3,209	782	24.4
1-4 .....	5,413	1,232	22.8
5-19 .....	3,788	448	11.8
≥20 .....	3,940	933	23.7
Unknown .....	50	0	0.0
Total .....	16,400	3,395	20.7

TABLE 5.—Age-Specific Death Rates for California Measles Cases, 1980-1987 and 1988-1990

Age Group, yr*	Measles Cases by Year						P Value
	1980-1987			1988-1990			
	Cases, No.	Deaths		Cases, No.	Deaths		
		No.	%		No.	%	
<1 .....	503	0	0.0	3,209	17	0.6	.10
1-4 .....	739	2	0.3	5,413	34	0.6	.31
5-19 .....	2,003	0	0.0	3,788	3	0.1	.56
≥20 .....	776	1	0.1	3,940	21	0.5	.16
Unknown .....	12	0	0.0	50	0	0.0	--
All ages.....	4,033	3	0.07	16,400	75	0.5	.01†

\*For the years 1980 through 1986, cases were tabulated by slightly different age groups (≤14 months, 15 months through 4 years, 5 through 18 years, and ≥19 years). This table does not reflect these grouping differences.

†Mantel-Haenszel summary  $\chi^2$  P value.

\*For the years 1980 through 1986, cases were tabulated by slightly different age groups (≤14 months, 15 months through 4 years, 5 through 18 years, and ≥19 years). This table does not reflect these grouping differences.

†Mantel-Haenszel summary  $\chi^2$  P value.

The severity of illness for medical staff cases paralleled that observed for adult cases overall. Four workers with pneumonia required ventilatory support, and encephalitis developed in two, one of whom was left quadriplegic. Three health care workers died.

#### Outbreaks With Exceptional Mortality

During the course of this epidemic, two outbreaks had exceptionally high case-fatality rates. The first of these was an outbreak of 61 cases among Samoan children in Los Angeles and Orange counties in the winter and early spring of 1989. Transmission occurred primarily within and among extended families and at church gatherings. None of the patients old enough to have received measles vaccine had been immunized. Pneumonia developed in 24 (40%) of these children, and 6 (10%) died. Case-fatality rates by age group were 10% for infants younger than 12 months (1 of 10 patients) and 17% for patients aged 1 to 4 years (5 of 29 patients). All 22 patients aged 5 years and older survived.

The second outbreak occurred between mid-summer 1989 and late spring of 1990 among Southeast Asian children in Fresno County, with secondary spread to other Southeast Asian communities in nearby Stanislaus, San Joaquin, and Sacramento counties. Of the 363 cases involved, 290 (80%) were in Hmong children. Of these children, 78 (27%) were infants younger than 12 months, 174 (60%) were 1 to 4 years old, and almost all of the remaining 13% were aged 5 to 9 years. Of note, 10% of the preschoolers and 55% of the school-aged children had had measles immunization at 12 months of age or older. Of these infants and children, 30% were admitted to hospital and 13 died (age range 5 months to 2½ years), yielding a case-fatality rate of 3.6%. All deaths were due to pneumonia with respiratory failure.

#### Epidemic Control Efforts

Both the CDHS and local health departments pursued multifaceted epidemic control programs, although specific activities varied according to the epidemic's local characteristics.

*Investigation and follow-up of individual cases.* Individual case investigation and follow-up were undertaken

to identify household and other close contacts and to isolate and administer vaccine or immune globulin to those known or presumed to be susceptible. As the number of cases increased in heavily affected areas, this labor-intensive activity was given lower priority, with resources instead being focused on community-wide control efforts.

#### Institutional outbreak control programs.

- *Schools and child care centers*—All unimmunized students were identified and notified that they must be immunized immediately or be excluded from school attendance. In 350 schools and child care centers that had measles cases or were threatened by measles outbreaks, approximately 6,000 (2.1%) of 280,000 pupils were identified as unimmunized and received exclusion notices. In at least 11 secondary school outbreaks, voluntary (9 schools) or mandatory (2 schools) reimmunization programs were undertaken for pupils who had been immunized at age 12 to 14 months (because of the lower efficacy of vaccination at this early age<sup>4,5</sup>) or who had received only one dose of measles vaccine. At least 12,000 pupils were reimmunized at special clinics held at or near these schools.

- *Colleges*—At least 11,500 students and staff members were immunized in voluntary or mandatory immunization programs at colleges having measles outbreaks. Several of these programs included voluntary reimmunization of students who had a history of only one measles vaccine dose.

- *Detention facilities*—Mandatory or voluntary immunization programs for inmates and staff members were held in 36 jails, prisons, or other detention facilities with measles outbreaks; at least 46,000 persons were immunized through these programs.

- *Health care facilities*—Many hospitals and medical clinics conducted one or more of the following: immunization of exposed, susceptible patients and staff; voluntary or mandatory immunization programs for staff; and voluntary measles immunization for all children aged 1 through 4 years brought into the facility for any reason (unless immunization was medically contraindicated or the child had documented prior immunization).

#### Community-wide outbreak control programs.

- *Immunization schedule changes*—In 11 counties

having measles outbreaks, the recommended standard age for measles-mumps-rubella immunization was lowered from 15 to 12 months of age. In 1990 all public immunization clinics in the nine most heavily affected counties began administering monovalent measles vaccine to all infants at 6 to 11 months. More than 36,000 infants were vaccinated between mid-1990 and early 1991. Parents of these infants were instructed to bring them back for their routine dose of vaccine at age 15 months.

- *Expansion of public immunization clinic services*—Measles immunization services in local health department clinics and in many nonprofit community clinics were augmented (as resources allowed) by increased staffing and hours of clinic operation. In addition, a variety of special immunization clinics were held. Door-to-door residential immunization programs were conducted in some high-risk areas.

- *General publicity*—Multilingual messages urging families to immunize their children were widely disseminated, using general news releases; presentations in churches, English-as-a-second-language classes, and community centers; mailings to Aid to Families with Dependent Children and Medi-Cal (California's Medicaid) clients; and distribution of leaflets or posters in markets and other retail outlets, libraries, laundromats, farm labor camps, churches, community centers, Women Infants and Children food supplementation clinics, medical care facilities, welfare offices, and other sites.

It is not possible to evaluate precisely the effect of community-wide control efforts because no outbreak was allowed to continue unchecked to provide a basis for comparison. The fact that the epidemic persisted for three years underscores the difficulty that these outbreak control efforts had in combatting the epidemic.

### *Cost of the Epidemic*

Based on a 1989 Los Angeles County survey finding that measles hospital admissions averaged five days at a mean cost of \$1,200 per day,<sup>6</sup> the cost for the 3,390 measles hospital admissions in 1988 through 1990 was estimated at \$20.34 million. Assuming that all 16,400 reported cases involved at least one outpatient visit each, at an average cost of \$80, the total outpatient medical care cost is estimated at \$1.31 million.

Comparing observed with expected usage of CDHS-supplied measles vaccines in public programs during the epidemic period indicates that more than 370,000 vaccine doses were used in epidemic control programs, for a vaccine cost of more than \$5 million. Other costs included an estimated \$2.0 million spent by local health departments for extra staffing of special immunization clinics, case investigation, and other disease control activities and \$2.2 million in state funds specifically appropriated in 1990 for immunization clinic expansion.

Total expenditures for direct medical care and outbreak control activities are conservatively estimated at \$30.9 million. This figure is certainly an underestimate, and it does not include indirect costs such as lost income and productivity by working adults who became ill or

who missed work to care for ill children, the lifetime income and productivity loss for the 75 persons who died, and the productivity loss to local health departments and medical care facilities resulting from diverting staff from other activities to help with epidemic control.

### **Discussion**

Campaigns to implement and rigorously enforce school immunization laws and to strengthen measles surveillance and outbreak control efforts were successfully executed across the United States in the late 1970s. As a result, many people hoped that indigenous measles transmission would be eliminated from the United States in the early 1980s. Clearly this has not happened, and California's epidemic in 1988 through 1990 was part of a larger national epidemic.<sup>2</sup>

In reviewing the data presented here, it is important to recognize their limitations. Measles cases were ascertained by a passive surveillance system, and substantial underreporting of cases almost certainly occurred. Only a few cases were laboratory confirmed, so it is likely that some illnesses other than measles were mistakenly included among the epidemiologically confirmed cases. Further, among reported cases, not all of the information sought on case report forms was consistently gathered as the caseload overwhelmed local health department resources in the more heavily affected areas. Despite these limitations, the principal features and implications of the epidemic are clear.

During the 1980s, measles outbreaks in the United States continued to occur in two principal forms: secondary school outbreaks, in which most patients were reported as having been immunized at or about 12 months of age, and outbreaks affecting unimmunized preschool-aged children in low-income communities.<sup>7</sup>

The number of cases occurring among toddlers (2,631 patients aged 6 to 11 months and 3,014 patients aged 12 to 23 months) underscores both the need for a vaccine that is more effective in small infants and the need for young children to be vaccinated as soon as they reach immunization age. A measles vaccine that could be given routinely with a high level of efficacy at 9 months of age or younger, such as the Edmonston-Zagreb strain vaccine currently under evaluation,<sup>8</sup> may prove to be helpful in addressing the former need, while the latter requires that greater efforts be directed toward achieving universal immunization. Based on the number of patients having no history of measles vaccination, as many as 65% of the 16,400 reported cases and deaths—that is, 10,660 cases and possibly 49 deaths—might have been prevented by universal immunization.

The site of exposure was not definitively identified for most cases, although most transmission appeared to occur outside of institutions. Next to households, medical care facilities were the most commonly identified transmission site. A case-control study undertaken in a large inner-city hospital in Los Angeles County revealed that unimmunized preschool-aged children had a fivefold increased risk of measles developing in the two weeks after visiting



the emergency department.<sup>9</sup> Another Los Angeles-based study documented patient-to-staff and patient-to-patient measles transmission.<sup>10</sup> These data underscore the need for medical care facilities, especially emergency departments and acute care clinics, to aggressively adhere to disease prevention guidelines. The fact that 23% of the medical staff members infected were born before 1957 also illustrates that medical facility measles immunization policies should not be restricted solely to young adults.<sup>10</sup> Indeed, medical care facilities must ensure that all health care workers are immune to measles.

A substantial number of cases did occur in schools despite the fact that only about 2% of California's primary and secondary school students were not immunized. If measles vaccine has a 95% efficacy in persons immunized at age 15 months<sup>11</sup> and 98% of students have received one vaccine dose, then only 93% of pupils will be immune. Because vaccine efficacy is slightly lower in persons immunized at age 12 to 14 months,<sup>4,5,12</sup> the overall school immunity rate may be less than 93% if a substantial proportion of pupils have been immunized at age 12 to 14 months. This is important because previous investigations have demonstrated that more than 95% of the population in secondary schools must be immune to prevent outbreaks of measles once infection has been introduced.<sup>13</sup> This again underscores the need for universal immunization.

One of the questions that arose during the epidemic was the efficacy of the measles vaccine. Three lines of evidence indicate that its efficacy was high. First, despite the many introductions of measles into schools that must have occurred (over 3,500 cases in persons aged 5 to 18 years), few large school outbreaks followed. Most cases in school-aged children resulted in very little, if any, school transmission. Only a handful of school outbreaks with more than three cases are known to have occurred. Second, a rough estimate of measles vaccine efficacy (VE) in school pupils can be made using the formula:

$$VE(\%) = [(PPV - PCV) / PPV(1 - PCV)] \times 100$$

where PPV is the proportion of the population vaccinated and PCV is the proportion of cases vaccinated.<sup>14</sup> Surveys of kindergarten entrants and older pupils conducted annually in California over the past decade indicate that 97% to 98% of pupils in grades kindergarten through 12 have been immunized against measles. Of the school-aged measles patients in this epidemic, 45% had been immunized. Using these two values in the above formula results in a measles vaccine efficacy estimate of more than 98%. Third, a study undertaken in California in 1990 comparing infection rates between immunized and unimmunized preschool-aged household contacts of measles cases demonstrated a vaccine efficacy point estimate of 95% (95% confidence interval, 89% to 97%).<sup>11</sup> Thus, it is clear that the vaccine was working well, and the major factor contributing to this epidemic was that too few children had been vaccinated.

A remarkable feature of this measles epidemic was the high frequency of serious illness and complications

compared with what has been recorded for other measles epidemics in developed countries.<sup>15,16</sup> And the actual complication rate may have been higher than reported here. For example, a special investigation of children aged 1 to 5 years in late 1989 and 1990 found rates of complications higher than those shown in Table 3; that investigation found complication rates for pneumonia of more than 10%, for diarrhea of 5%, and for otitis media of more than 35%.<sup>11</sup>

Measles is generally more severe in infants, young children, and adults than in school-aged children<sup>16</sup>; these higher-risk age groups made up a greater proportion of California's cases from 1988 through 1990 than in earlier years. Tables 3 and 5 indicate that for pneumonia, diarrhea, and death, age stratification of cases did not eliminate the relatively increased disease severity. Changes in the racial or ethnic composition of cases might partially account for the increased illness severity. Unexplained high case-fatality rates were recorded among both Samoan (10%) and Hmong children (3.6%). If the 19 Samoan and Hmong fatalities are subtracted from the 75 total deaths, the age-stratified summary case-fatality rate for the epidemic period remains significantly higher than that for the period from 1980 through 1987 (Mantel-Haenszel summary  $\chi^2$   $P$  value = .007).

Evaluating the role of race or ethnicity as a factor in the epidemic's increased severity is difficult because this variable was not recorded on most case reports for most of the 1980s. Surnames were recorded, however, so, as a surrogate for actual race or ethnicity data, comparisons were made for Hispanic surnames. This is a reasonable surrogate in view of the fact that 80% of California's Hispanic population immigrated from Mexico or was descended from Mexican immigrants.<sup>17</sup> Complication rates among measles patients with Hispanic surnames, stratified by age, are compared for 1987 and 1988 through 1990 in Table 6. As with cases of all racial or ethnic groups combined (Table 3), pneumonia and diarrhea rates were significantly higher for Hispanic patients during the epidemic. Age-specific hospital admission data for Hispanic cases were compared for 1987 and 1988 through 1990 (Table 7). For epidemic-period cases, 23% required admission to hospital compared with 3.7% of the 1987 cases. Differences in age composition do not account for this difference. Likewise, in the eight-year period 1981 through 1987, only two Hispanic measles patients are known to have died, compared with 27 of the 6,524 Hispanic cases occurring in 1988 through 1990. Thus, for Hispanic persons, most indices of illness severity rose during the epidemic, which suggests that a change in racial or ethnic composition of the population is not the major explanation for the observed increase in illness severity.

Other possible explanations for the apparent increased measles severity include underreporting of mild cases during the epidemic and underreporting of measles complications before 1988. Currently available data do not allow us to clearly corroborate or refute either possibility. The fact that otitis media, unlike pneumonia and diarrhea,



TABLE 6.—Complications by Age Group for California's Hispanic Measles Cases, 1987 and 1988-1990

Complication and Age Group, yr	Measles Cases by Year						P Value
	1987*			1988-1990			
	Cases, No.	Complication Present		Cases, No.	Complication Present		
		No.	%		No.	%	
Pneumonia							
<1 .....	15	0	0.0	1,755	139	7.9	.62
1-4 .....	40	1	2.5	2,466	233	9.5	.17
5-19 .....	38	0	0.0	1,250	54	4.3	.19
≥20 .....	16	1	6.3	1,030	72	7.0	.69
All ages .....	109	2	1.8	6,501	498	7.7	.05†
Diarrhea							
<1 .....	15	1	6.7	1,755	259	14.8	.71
1-4 .....	40	1	2.5	2,466	360	14.6	.03
5-19 .....	38	0	0.0	1,250	132	10.7	.03
≥20 .....	16	1	6.3	1,030	144	14.0	.71
All ages .....	109	3	2.8	6,501	895	13.8	.002†
Otitis Media							
<1 .....	15	1	6.7	1,755	147	8.4	1.00
1-4 .....	40	1	2.5	2,466	199	8.1	.37
5-19 .....	38	0	0.0	1,250	23	1.8	1.00
≥20 .....	16	1	6.3	1,030	4	0.4	.07
All ages .....	109	3	2.8	6,501	373	5.7	.44†
Encephalopathy							
<1 .....	15	0	0.0	1,755	4	0.2	1.00
1-4 .....	40	0	0.0	2,466	6	0.2	1.00
5-19 .....	38	0	0.0	1,250	0	0.0	Undefined
≥20 .....	16	0	0.0	1,030	3	0.3	1.00
All ages .....	109	0	0.0	6,501	13	0.2	.44†

\*Information was available for only 92% of 1987 cases.

†Mantel-Haenszel summary  $\chi^2$  P value.

\*Information was available for only 92% of 1987 cases.

†Mantel-Haenszel summary  $\chi^2$  P value.

was not reported more frequently in 1988 through 1990 (Table 3) seems to argue against changes in reporting of cases or complications as an explanation. Further, measles case reporting among medical facility staff should be fairly complete, yet the complication and case-fatality rates for this population were also notably high during 1988 through 1990.

In addition to the above-noted factors, constrained access to medical care among low-income Hispanic persons may have contributed to the occurrence of complications and to the increased disease severity. Unfortunately,

available data do not allow us to evaluate this issue. Further investigation in this regard might be productive in answering questions about the importance of ready access to medical care for diseases like measles.

Local and state health department efforts to control this epidemic had an indeterminate effect. Constraints hampered each type of control measure. For example, the size of the epidemic overwhelmed the capability of local health departments to do detailed follow-up of individual cases, although individual case investigation (to identify and immunize susceptible contacts) is an inherently weak

TABLE 7.—Hospital Admissions by Age Group for California's Hispanic Measles Cases, 1987 and 1988-1990

Measles Cases by Year							
Age Group, yr	1987*			1988-1990			P Value
	Cases, No.	Hospital Admissions		Cases, No.	Hospital Admissions		
		No.	%		No.	%	
<1 .....	15	0	0.0	1,755	428	24.4	.03
1-4 .....	40	2	5.0	2,466	621	25.2	.003
5-19 .....	38	0	0.0	1,250	175	14.0	.01
≥20 .....	16	2	12.5	1,030	268	26.0	.39
All ages .....	109	4	3.7	6,501	1,492	23.0	<<.01*

\*Information was available for only 92% of 1987 cases.  
†Mantel-Haenszel summary  $\chi^2$  P value.

\*Information was available for only 92% of 1987 cases.

†Mantel-Haenszel summary  $\chi^2$  P value.

strategy for a disease as infectious as measles, and particularly when exposure so often occurs in anonymous group settings, such as supermarkets, buses, and the like. Control efforts for institutional outbreaks dealt with more readily identifiable and accessible target populations, but jail and prison disease outbreaks presented other difficulties. Because inmates did not have immunization records available and because the often rapid turnover in these institutions provided a continuing supply of susceptible persons, the only effective control measure was mass immunization of all current and incoming inmates for at least one incubation period after the last measles patient was removed. Such efforts were costly in both vaccine and staff time. Initial high inmate refusal rates in some of the voluntary immunization programs necessitated mandatory immunization programs for these persons.

Because most measles transmission in this epidemic appeared to be occurring in the community at large, community-wide efforts were a major containment strategy. Substantial problems were encountered in this regard, however. Resource limitations, in particular, restricted activities at both the state and local levels.

From the epidemic's beginning in 1988 through the spring of 1990, the CDHS had recurring shortages of funds to purchase vaccine. This limited the agency's outbreak control efforts and precluded administering monovalent measles vaccine to 6- to 11-month-old infants in public immunization clinics in high-incidence areas until late in the epidemic. In addition to vaccine funding problems, staffing limitations in local health departments restricted the ability to expand immunization services. In the late winter and spring of 1990, as the epidemic reached its peak, the CDHS was able to focus the attention of the California legislature on this problem, resulting in supplemental appropriations of \$6 million to procure additional measles vaccine and \$2.2 million to augment immunization activity by local health departments and nonprofit community clinics.

The second major problem encountered with community-wide epidemic control efforts was difficulty motivating parents in target populations to have their children immunized. Special immunization campaigns repeatedly produced disappointing results despite extensive multilingual publicity efforts. The best responses occurred in communities that had just been inundated with news stories about measles deaths. The farther away these messages were, either in time or geographically, the poorer the public response to immunization campaigns.

It must be recognized that even with adequate resources and good public response to immunization campaigns, the control of measles epidemics is difficult. Measles is a highly contagious, rapidly spreading infection that has repeatedly demonstrated its ability to erupt even in the presence of high population immunity levels.<sup>5,13,18</sup> Over the past several years, measles epidemics similar to California's have arisen and persisted for prolonged periods in other parts of the country.<sup>7,19,20</sup> Indeed, none of the epidemic control efforts tried in California or elsewhere in the United States have proved to be rapidly

and consistently successful in halting widespread outbreaks of this disease.

The key to preventing future measles epidemics is raising immunization levels among preschool-aged children, especially in low-income communities. Unfortunately, improvement in this regard has been elusive. Surveys conducted in California<sup>21</sup> and elsewhere in the United States<sup>22</sup> indicate that only 70% of children have been immunized against measles by their second birthday, with this figure being as low as 55% in low-income communities. This situation has persisted despite a wide variety of efforts made by government agencies, the private medical sector, and volunteer groups.<sup>22</sup> To improve this situation substantially, we need a measles vaccine that is effective in infants younger than 12 months, better accessibility of immunizations for low-income families, and more effective methods of motivating parents to have their young children immunized. Measles outbreaks and epidemics such as this one will continue to occur unless population immunization rates can be increased and maintained at essentially universal levels.

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